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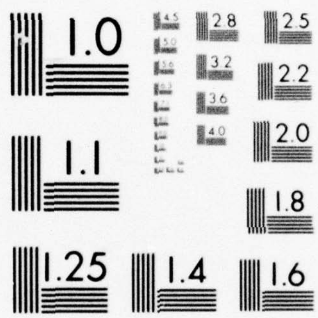
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by

(10) John Francis Bouldry

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DESIGN OF TWO HIGH GAIN, LOW PROFILE HELICAL ANTENNAS FOR OPERATION AT 918 MHz

by

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Submitted in partial fulfillment of the requirements for the degree of

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ABSTRACT

Two helical antennas were designed, fabricated and tested to permit tanks or tracked vehicles to function with a high gain, low profile antenna field pattern for a telemetry system operating at 918 MHz. The electrical properties of the helical antennas were compared to the system's dipole antennas in an attempt to enhance the operating performance of the RMS II/SCORE system. Field measurements were made under the controlled conditions of an antenna field pattern range and while the RMS II system was operational. Antenna properties of gain, beamwidth and efficiency as well as physical size and installation locations were considered for possible inclusion of helical antennas in the telemetry system.

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I. INTRODUCTION

A. BACKGROUND

The Range Measurement System utilizes pulsed radio-frequency multilateration to provide position location information from multiple aircraft, ground vehicles or personnel equipped with transponders. In addition, the Simulated Combat Operations Range Equipment provides aircraft velocity, acceleration, attitude and air data as well as improved position location. When operated in concert, the user is provided with a ranging and digital message-communication system for the evaluation of tactical field maneuvers. To accomplish this, a combination of six types of units are employed which may be portable, semi-fixed or rigidly fixed. Information is passed through the system either by means of an RF link or by hard wire [1]. The designated RF operating frequency is 918 MHz and a frequency bandwidth of 10 MHz is used.

Successful operation of the system is dependent upon the user's confidence that his particular requirements for coverage and accuracy will be satisfied. The accuracy of the RMS ranging instrumentation becomes a function of system-to-vehicle relationships which include geometry, dynamics, physical environment, and system hardware/software configuration. Sources of error for range data may also result from multipath propagation effects, antenna pattern null structures, terrain shadowing, interfering signals, or other unforseen disturbances.

B. THESIS OBJECTIVE

Presently the RMS system has dipole antennas installed for receiving and transmitting inquiries and responses for range information. Since the operating frequency for these transmissions is 918 MHz, the effects of the terrain produce standing waves on the field of play and, hence, signal nulls. Should the dipoles be made more directional, the effects of signal nulling would decrease. A second factor for consideration arises in that the antennas are six feet in heighth and are susceptible to damage when mounted on vehicles and subsequently driven through high underbrush or beneath trees. An alternate approach is to investigate the feasibility of using circularly polarized antennas to change the signal nulling components. Further, these antennas could result in a lower antenna profile affording a longer antenna survivability.

The objective of this work was to examine the possible inclusion of circularly polarized antennas into the RMS system for use on ground vehicles. Specifically, helical antennas were identified for study as they yield components with the desired polarization. Antennas were designed and constructed for both the axial and normal modes with emphasis placed upon selective location of main lobes in the antenna field patterns. Finally, the antennas were evaluated for enhancement of the operating performance of the RMS system.

II. THEORY

A. INTRODUCTION

The helix is a fundamental geometric form. As such, it has many applications in several branches of physics and engineering. For example, in mechanical engineering the helix or coil spring is a common device; in electrical systems the helical coil or inductor is a typical circuit element; and in dynamics, particles often flow in helical patterns.

The theoretical investigation of helical antennas is well known and complete [2], [3]. These antennas may be regarded as the connecting link between the linear antenna and the loop antenna. The helical antenna is thus the basic form of antenna of which the linear and loop antennas are special cases. Therefore, a helix of fixed diameter collapses to a loop as the spacing approaches zero and a helix of fixed spacing between turns straightens out into a linear conductor as the diameter approaches zero.

B. MODES OF RADIATION

Helical antennas are capable of radiating in several modes. The two most common modes are the axial mode and the normal mode. These two modes are most appropriate for

application in the RMS system and, therefore, will form the basis for designs.

1. Axial Mode

In the axial mode of radiation the field is maximized in the direction of the helix axis and the polarization is circular. This mode is generated when the helix circumference is of the order of one wavelength. There are two unique and outstanding characteristics of this mode. First, for a given helix, this mode is stable over a relatively wide frequency range [3]. Since the antennas must be functional over a 10 MHz bandwidth, this feature is very desirable. Secondly, the axial or beam mode can be produced with great ease. Because the actual dimensions for this mode are non-critical, a helical beam antenna is one of the simplest types of antennas to construct. Axial mode radiation patterns may be formed from helices of uniform cross section or from helices which are tapered.

2. Normal Mode

In the normal mode of radiation, the field is a maximum in a direction perpendicular to the helix axis and, for a certain relationship between the spacing between turns and the diameter, the field is circularly polarized. For the normal mode the dimensions of the antenna must be small compared to the wavelength [2]. This requirement must be met as the physical dimensions are more critical for this case than for the axial mode. If these critical dimensions are not met, bandwidth and antenna efficiency suffer greatly and the resulting radiator will degrade the performance of the transponder. Normal mode helices are often not practical and inconvenient. Some larger normal mode helical

antennas require phase shifters placed between successive turns in order to maintain uniform, in-phase current distributions.

C. GEOMETRIC DESCRIPTION

Helical shapes are frequently used in scientific and engineering endeavors and are therefore commonplace. When used in the capacity of a radiating structure, the physical dimensions of the helix dictate the type of mode which will appear. With the physical dimensions playing such a key role in the helix, an antenna can be described using three parameters: the diameter, the number of turns and the pitch angle.

When specifying the helix diameter, this dimension is normally measured in free-space wavelengths. The diameter is measured from center to center of the material used in the construction of the helix.

The number of turns appearing in a circular helical antenna assists in determining several aspects of the antenna characteristics. First it has an influence on the size of the structure. As the number of turns increases, the physical length of the antenna increases also. More importantly, the number of turns has a profound bearing on the field pattern when the axial radiation mode is desired. The directivity of the antenna is proportional to the number of turns of the helix and inversely proportional to the beamwidth between the half-power points.

The pitch angle of the helix also is a factor in determining the physical size of the antenna. Small pitch angles yield long helical antennas. The parameters

determining the pitch angle include the spacing between successive turns, the helix circumference and the length of one turn. Combinations of these parameters in a simple Pythagorean relation result in the determination of the pitch angle. When the loop spacing is zero, the pitch angle is zero, and the helix becomes a loop. On the other hand, when the diameter is zero, the pitch angle is 90 degrees, and the helix becomes a linear conductor. By varying the pitch angle, the helical antenna can change its characteristics from a simple loop to a helix operating first in the axial mode then in the beam mode and, finally, to a linear conductor.

D. SPACING-CIRCUMFERENCE CHART

The design of helical antennas has been simplified when the spacing-circumference chart is utilized [3]. This design aid allows one to quickly determine the critical values of the antenna parameters. The chart is constructed in such a manner that it can be utilized knowing either the spacing or circumference in wavelengths or the length of one turn in wavelengths. Regions are marked on the chart indicating where the antenna parameters will combine to yield beam mode or normal mode radiation patterns.

The Spacing-Circumference Chart is reproduced and shown as Fig 1. The ordinate axis represents loops while the abscissa axis represents linear conductors. The remaining area between the two axes represents the general case of the helix.

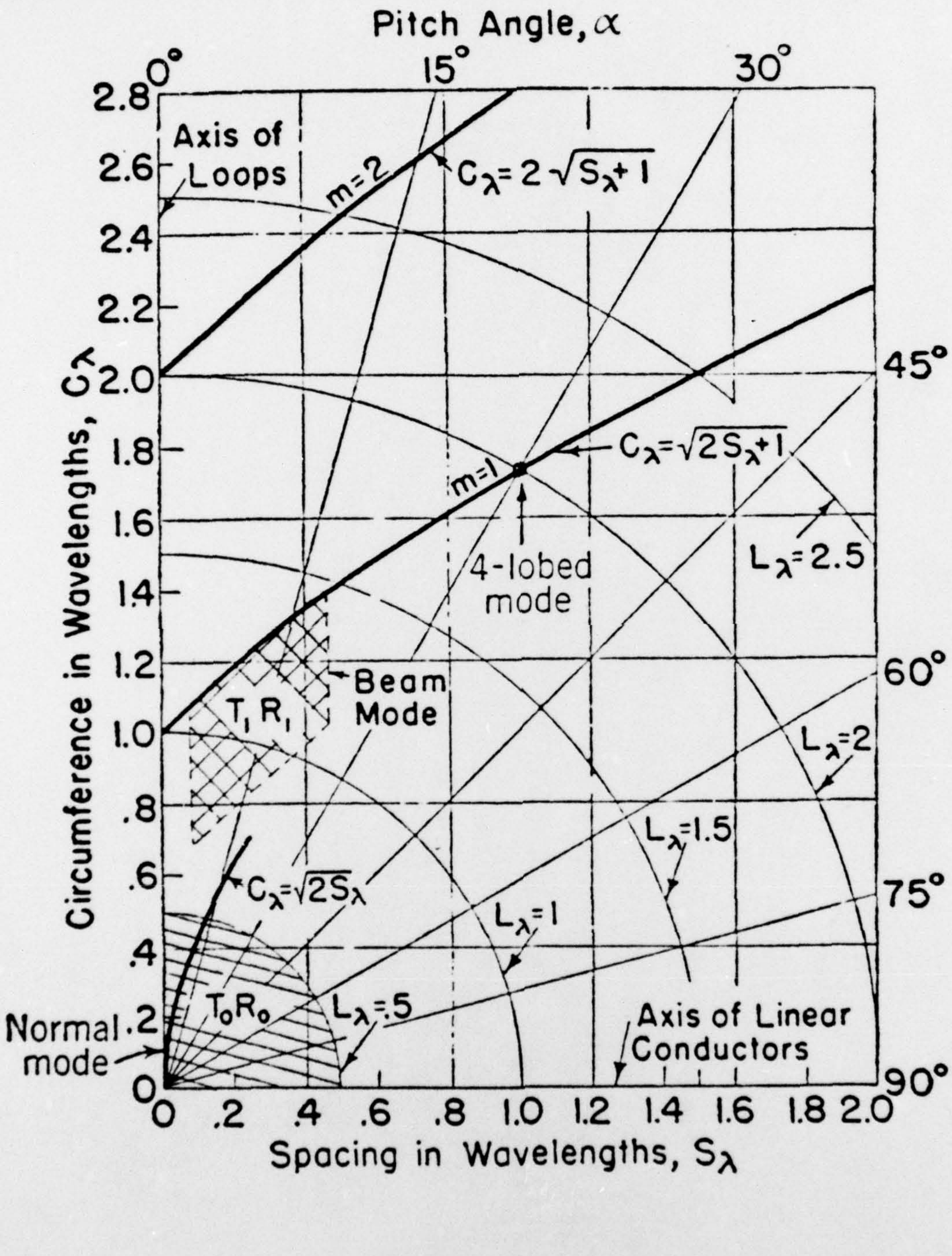

Figure 1 - SPACING-CIRCUMFERENCE CHART

E. GROUND PLANE REQUIREMENTS

The inclusion of a ground plane or reflecting surface assists the radiation in being focused in a specific direction. Ground planes may appear in several forms with the usual reflectors being solid plate, mesh screen, or spoke type. For experimentation purposes, the ground planes employed with the helical antennas were the solid plate type shaped as a square. Optimization of the reflector surface size involves changes in the reflector dimensions and this was most easily accomplished when working with rectangular shapes instead of the usual circular forms. Antenna patterns obtained from helical antennas radiating over square reflectors yielded field patterns with additional sidelobes. The appearance of these unexpected sidelobes resulted from the additional reflecting material located at each corner of the reflector which is not present in circular ground planes.

Ground planes for helical antennas should be at least one-half wavelength in diameter [2]. The helix is operated in conjunction with the ground plane and is energized by a semi-rigid coaxial transmission line. The inner conductor of the line terminates in the helix and the outer conductor terminates in the ground plane. Such an arrangement necessitates an insulator being placed between the reflector and the vehicles which are the support mechanism for the helical radiators.

F. IMPEDANCE MATCHING REQUIREMENTS

The requirement for matching the design antenna with the RMS system was dictated by the transmission cables currently used. The cables presently installed are RG-58C/U which have a characteristic impedance of 50 ohms. Baluns were constructed to accomplish the impedance matching in which the impedance step-up ratio was 4 : 1 [4]. The length of the balun was one-half wavelength modified by a factor accounting for propagation through the transmission medium.

G. ANTENNA SPECIFICATIONS

Helical antennas can exhibit a significant advantage over the dipole antennas presently used in the RMS system. This advantage is realized when the transmitted electromagnetic energy is distributed in directions where known A station interrogators are located. The implication here is that little RF energy will be radiated in directions where there are no A units positioned and will reduce the possibility of RF energy contributing to multipath effects. An analysis of the terrain features at Fort Hunter Liggett indicates that antenna field patterns directing energy upward at an elevation of 10 to 15 degrees should be sufficient for the main lobes to be directed at the A stations. Elevation angles for the main beam may be acquired through proper antenna design considerations coupled with the reflecting advantages which a ground plane can provide.

Two antennas were proposed which demonstrated the flexibility of the helical antenna. The first design was based upon the normal mode of radiation. This design employs only one antenna with the pattern being omnidirectional in the E phi plane. The antenna should be located in a prominent position on top of a tracked vehicle or other ground vehicle. The second design employs several small helices in the axial radiation mode all located around the vehicle and tilted slightly at an angle of 10 to 15 degrees. Depending upon the 3 dB beamwidth, 3 to 5 antennas could adequately cover the vehicle. With the antennas located at the periphery of of the vehicle, a power splitter would be required to feed the antennas.

The first design was attained by choosing antenna parameters slightly outside the well-defined region for the normal radiation mode. This slight deviation allows the field pattern to have conical lobes. Further, when utilized with a ground plane, these conical lobes are elevated about 15 degrees above the horizontal with the antenna in the vertical position. To achieve this result, the antenna had four turns, a pitch angle of 24 degrees, and a circumference of 1.25 wavelengths. These parameters produced a helical antenna whose radius was 6.5 cm and whose vertical height was 63 cm. The 3 dB beamwidth of the main lobe in the theta direction of the E field is 28.05 degrees and the terminal resistance for this antenna is 175 ohms.

The design utilizing several helical antennas results in an antenna which was significantly smaller in size. Parameters were selected for this antenna such that the transmission mode was located in the axial region of the Spacing-Circumference Chart. This antenna produced a substantial main lobe along the axis with two significantly smaller sidelobes at the antenna base. To achieve this

pattern, the helix again had four turns but the pitch angle was reduced to 12 degrees and the circumference reduced to .85 wavelengths. As a consequence, the overall size of the axial mode antenna was greatly decreased when compared to the normal mode antenna. The radius of the axial mode antenna is 4.4 cm and its height is 17.5 cm. When looking at the theta plane of the E field, a 3 dB beamwidth of 68.4 degrees was attained. The radiation resistance was calculated to be 119 ohms. With a beamwidth of nearly 70 degrees, at least four and perhaps five antennas will be required for adequate coverage of a vehicle.

Extending the application of helical antennas from vehicle mounting to helmet mounting has been suggested. Individual maneuvering personnel also require the benefits of circular polarization. The normal mode helical antenna with its field pattern seems correct for use with personnel. However, the physical size of the antenna and its associated ground plane make it totally impractical for either helmet mounting or positioning in some fashion atop a back pack. The smaller axial mode antenna has the correct physical size for use with personnel. The degrading factors in this case are that several antennas must be utilized in order to achieve adequate coverage and, more importantly, the main lobe direction with respect to the helix axis is not correct. From these considerations, use of either helical antenna as a replacement for the current helmet mounted dipole antenna will not be recommended.

The concept of radiation resistance and ohmic losses were used to arrive at a value for the efficiency of the antennas. Radiation resistance is related to the power being dissipated [6]. Heat losses detract from the total power available for radiation and therefore reduce antenna efficiency. In general, radiation resistance can be expressed as the product of a constant and an antenna

parameter. The common feature of the antenna parameter is that it usually is a linear dimension of the antenna expressed in wavelengths. For the case of helical antennas, the radiation resistance can be expressed as [2]

$$R=140C_{\lambda},$$

where C_{λ} is in wavelengths.

Reducing the radiating efficiency are those factors which contribute to heating. Heating losses, or ohmic losses, are associated with the material properties of the antenna. The electrical resistive value for copper is 5.82 microhms-cm and the value for aluminum sheet metal is 5.75 microhms-cm [5].

In addition to pure material losses, other losses must also be taken into account. Losses result from each insertion of a coaxial cable connector/adapter into the transmission path, propagation through the semi-rigid coaxial cable and also from the physical union of the radiating element with the coaxial feed.

Computing both the radiation resistance and the ohmic losses results in the efficiency values of 51% for the normal mode helix and 57% for the axial mode helix.

III. EXPERIMENTAL PROCEDURE

A. ANTENNA CONSTRUCTION

Two helical antennas were constructed adhering to the established specifications. Both antennas were considered as prototype, experimental versions of a future antenna suitable for rapid assembly. Accordingly, the fabrication and basic design was formulated so that antenna ground plane dimensions could be reduced for testing purposes without having to construct a separate antenna.

The radiating element was formed from 1/4 inch copper tubing. Hollow copper tubing was selected as it could be easily shaped into a helix without deformation of the material due to compression at the interior of the helix. Copper tubing also was an excellent interfacing material with the semi-rigid coaxial cable which also was constructed from copper.

Supporting the helix was a center section of non-conducting plastic tubing. Attached to the cyclindrical support tube were 1/2 inch plastic spacers which provided the helical element with a mold for maintaining the correct value for the radius. The spacers were attached to the support structure with epoxy. Likewise, the radiating element was bonded to the spacers with epoxy.

The ground plane was constructed from 1/32 inch aluminum sheet metal. With the ground plane rigidly attached to the

helix, changes in the ground plane size were quickly made as the reflecting surface was a square instead of the usual circular disc surface. Initially the size of the reflector was two wavelengths long and was gradually reduced until a desired field pattern resulted.

Semi-rigid, unshielded coaxial cable interfaced with the system's RG-58/U coaxial cable. The unshielded cable was attached beneath the ground plane and its center element connected to the helix. This arrangement allowed the helix and the ground plane to be driven by the unshielded cable.

B. IMPEDANCE MATCHING TECHNIQUE

The antenna design must also permit a balanced interfacing of each antenna with the RMS system. The importance of this consideration rests in knowing that only a small percentage of the transmitted power actually gets reflected back into the transmitter. A balun was built as specified in Reference 4 whose function was to effect a smooth transition when the signal passed the unbalanced transmission line-radiating element interface. The balun assembly was connected such that the center feed of the coaxial cable would drive the radiating element and the balun feed would be grounded to the reflecting plane. It was necessary to insulate the ground reflector surface and the radiating element from contact with any other portion of the balun or coaxial cable.

Standing wave ratios were found for both antennas utilizing the HP 8410S Microwave Network Analyzer System as depicted in Figure 2. VSWR's were found over a range of 10 MHz centered around 918 MHz. The results were plotted on Smith Charts and included in Appendix A. Testing indicated

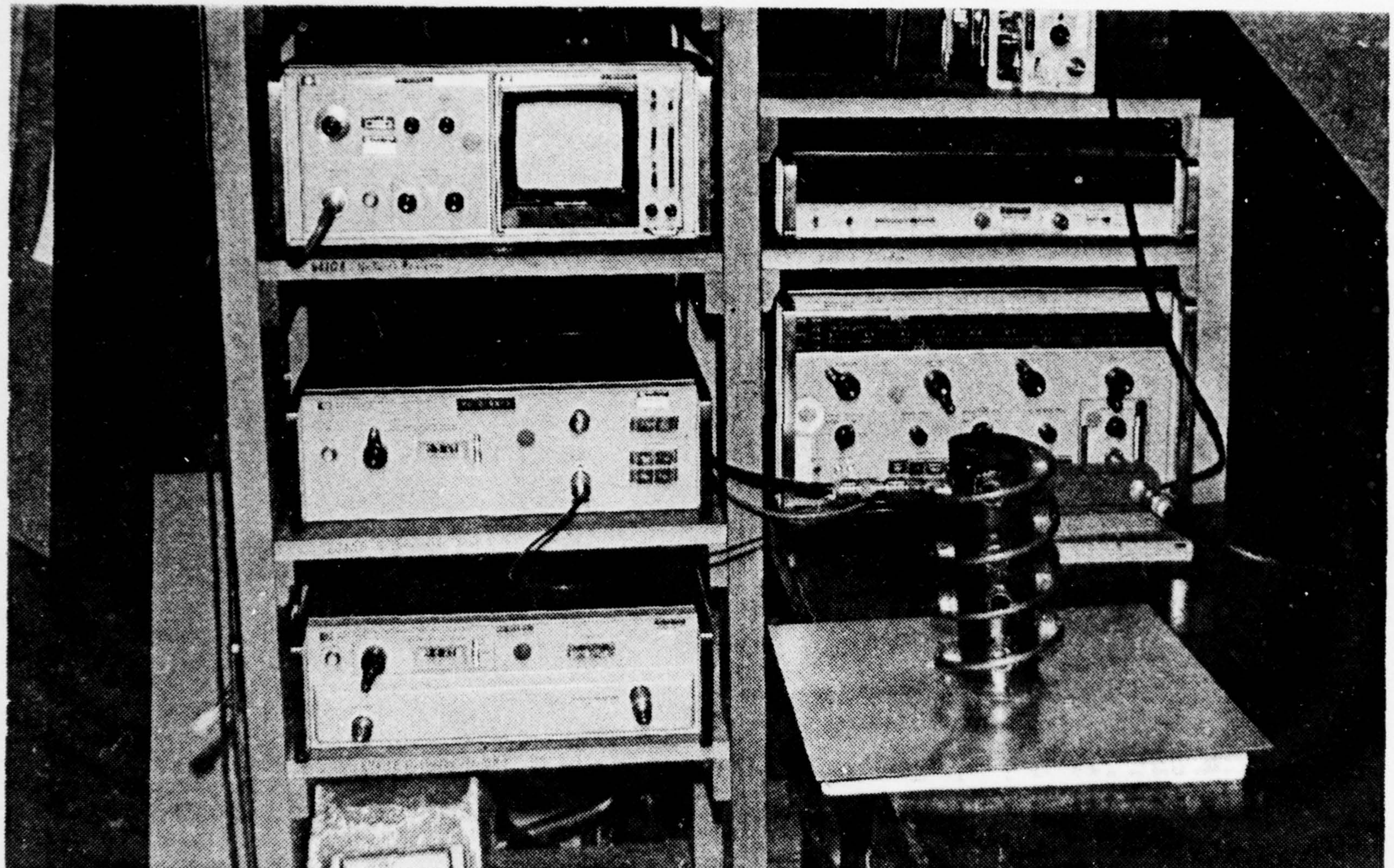

Figure 2 - PHOTOGRAPH OF NETWORK ANALYZER

that the variation of VSWR was from 1.1 to almost 1.25. Further testing resulted in the discontinued use of the balun as no significant benefit was derived from its use in reducing the standing wave ratio. At several test frequencies, the VSWR was actually lower without the balun connected.

The HP 8410S was particularly well suited for this investigation. This system has the capability of displaying an instantaneous Smith Chart reading which can quickly be converted to a standing wave ratio value or be used for a determination of the reflection coefficient.

C. FIELD PATTERN TESTING

Upon completion of the construction of each antenna, verification of the theoretical electromagnetic field characteristics was accomplished by recording the field patterns of each antenna. A small antenna range was used where the separation distance of the transmitting antenna and the receiving helical antenna was in excess of six wavelengths. The patterns recorded, therefore, were the far-field patterns of each antenna. Care was exercised to insure that both receiving helical antennas and the transmitting dipoles were the same vertical distance from the ground. Furthermore, adjustments to the mountings of the helical antennas were made in order that they be parallel to the transmitting antenna and perpendicular to the ground. Once in position for testing, the antennas were again checked to see that no misalignment or tilting had occurred while the antennas were rotated into position. The antenna range used for obtaining the field patterns is shown in Figure 3. Included in the photograph are the transmitting dipole and the receiving helical antenna.

Figure 3 - PHOTOGRAPH OF THE ANTENNA RANGE

Irregular and cyclic variations sometimes appear in the field patterns of the antenna under test due to ground reflections [5]. A common remedy to eliminate the nonuniform field at the receive antenna is to employ conducting fences to shield the antenna under test from any radiation reflected from the ground. Conducting fences were not included in the antenna range as the antennas were mounted high above the reflecting surface on pedestals. The recorded field patterns were void of any significant cyclic or irregular field fluctuations attributed to ground reflections. As indicated earlier, the additional sidelobes present in the field patterns were attributed to the additional surface area of the square ground plane which normally has a circular shape.

Field patterns were recorded only during the mid-morning hours. At this time of day the wind strength was minimal causing few sudden variations or oscillatory changes in antenna position.

Field patterns were drawn using the Scientific- Atlanta Model 1533 Polar Recorder. The recorder gain was adjusted to yield maximum deflection for the principle and significant sidelobes prior to recording. A line attenuator was also included in the recording scheme to allow 3 dB positions in the beam lobes to be located. All plots and half beamwidth points were drawn with the polar recorder moving in a clockwise direction. Early use of the polar recorder indicated that some play in the gear train was present but by restricting the motion of the recording device to only one direction, the error due to slack in the gear train was eliminated.

Field patterns were taken in the theta and phi directions. Both directions were the principle planes of

interest and are defined as such by Kraus in reference [2]. The field patterns were recorded with the transmitting dipole antenna stationary and the receiving helical antenna rotating at a slow, uniform rate in the designated plane.

Testing of the two helical antennas was extended from the antenna range to Fort Hunter Liggett where the Range Measurement System is currently operating. Evaluation of the helical antennas was conducted on two separate occasions under widely varying environmental conditions. The first evaluation period occurred during the early afternoon with temperatures averaging 80 degrees Fahrenheit. The interrogating A station was the mobile A unit and the responding player unit was the mobile B unit. Ranging pulses were transmitted to the B unit located from 600 to 1200 meters from the A unit. Included within the range variation was an elevational variation. With the interrogating A unit located atop a ridge, test sites included transmissions over a small tree to the B unit in the valley below and also across the valley to a test site located at approximately the same elevation.

A second experimentation period was scheduled during the evening. This afforded the experimenter an opportunity to observe the system operating under different propagation conditions found only at night. Evening temperatures varied between 55 and 60 degrees Fahrenheit during the test period. The interrogating unit was a hard wired, fixed A station and the receiving unit was the mobile B unit. The location of the A station was again atop a ridge. All B unit test positions were below the elevational level of the A station.

The test configuration of each antenna is shown in Figure 4 and Figure 5. A tripod was used to support the helical antennas and permitted the antennas to be evaluated at heights of 36 inches and 72 inches above ground level.

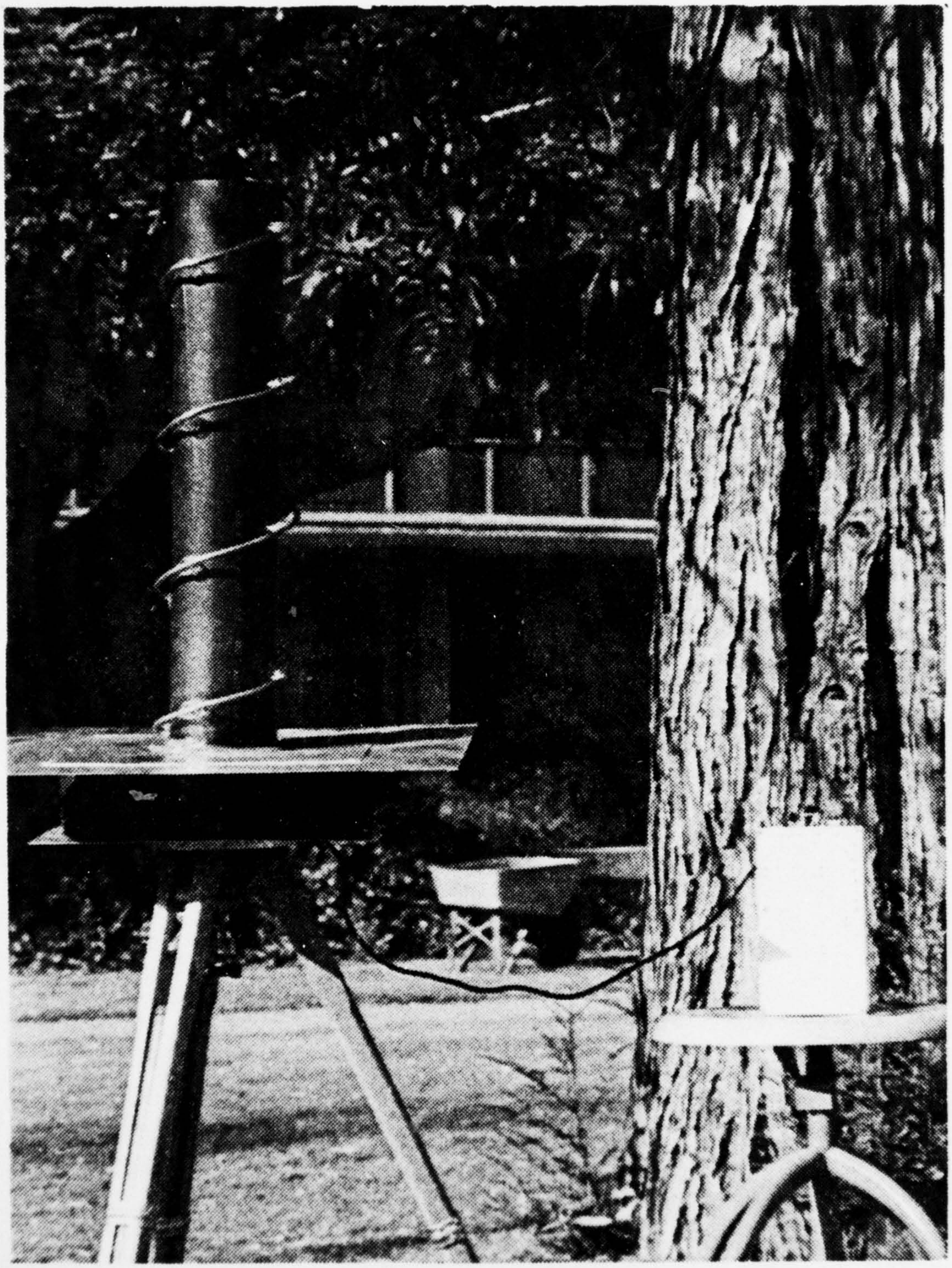

Figure 4 - FIELD TEST OF NORMAL MODE HELIX

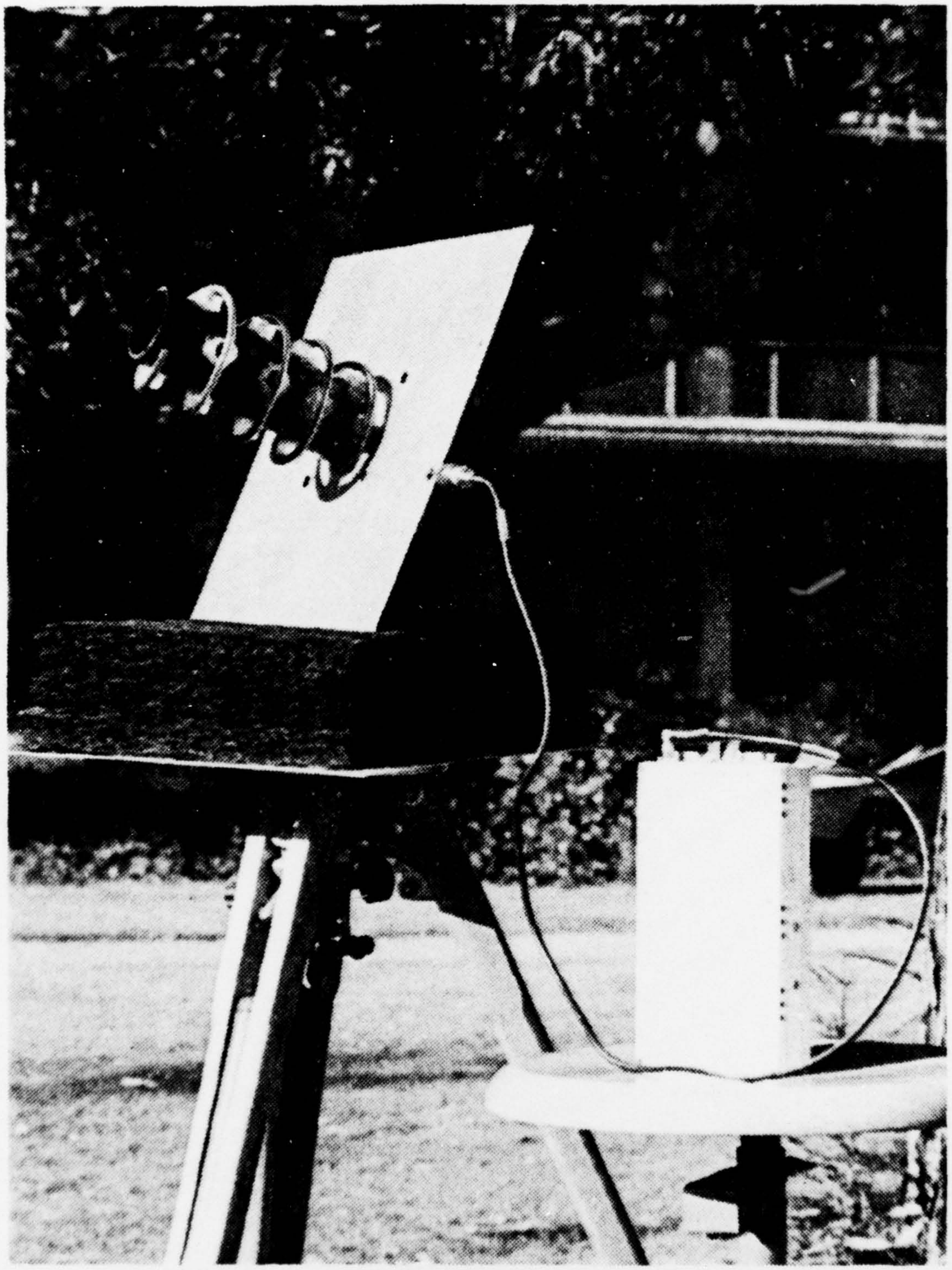

Figure 5 - FIELD TEST OF AXIAL MODE HELIX

An insulation material was placed between the ground plane of the helical antenna and the tripod. It was necessary to provide this insulation since the semi-rigid coaxial cable was exciting both the ground plane and the helical copper element. During both testing periods, several B units and several special coaxial cables for B unit to helical antenna connection were available. Testing was then able to be conducted using combinations of B units and system cables for evaluation of the helical antennas.

B unit test site locations were selected to test several features of the circularly polarized helical antennas. Some locations were chosen as foliage was directly in the transmission path between the interrogating unit and the responding B unit. Circularly polarized transmissions could then be evaluated against linear polarized transmissions in the presence of a naturally occurring attenuator. Within each location, the antenna height could be varied using the tripod thus yielding information concerning multipath effects due to slight changes in height above ground level. All tactical tracked vehicles experience this type of motion while maneuvering through open, rolling terrain. By making large changes in the elevation of the responding B units, further evidence of multipathing could be observed if signals reflected from the valley floors were interacting with the line of sight transmissions.

IV. PRESENTATION OF DATA

A. FIELD PATTERN RESULTS

Field patterns obtained from the antenna range testing verified the theory of helical antenna design as postulated by Kraus. The position of the sidelobes was correct although additional modification of the ground plane dimensions was required in the case of the normal mode antenna. In addition to verifying the field pattern for each helical antenna, it was observed that one quadrant of the field pattern was attenuated slightly from that which was expected. This characteristic of the antenna range was verified using dipole antennas as a reference and observing this same phenomena over a wide range of frequencies. This aberration was attributed to structures located a short distance from the antenna range and not considered a part of the antenna range test configuration. Additional dipoles and several different frequencies were used to insure that the source of the antenna field pattern asymmetry was not due to the radiation characteristics of one of the antennas under test.

The results of testing the normal mode helix indicate a 9.86 dB gain with an 8 dB gain margin in the theta plane over the system's dipole antenna presently used for transmissions from tracked vehicles. Almost the entire gain increase was achieved through focusing a maximum of transmitted energy in directions of expected A station locations. In order to achieve this result, the direction

of the two main lobes in the theta plane had to be 10 to 15 degrees above the horizontal. Normal mode antennas radiating with these characteristics would allow coverage to A stations located on distant ridge lines as well as to interrogators positioned close to the same elevational level as the B unit transponders.

Initial field patterns indicated two main lobes located approximately 170 degrees apart and projected outward from the antenna. The size of the square ground plane reflecting the radiation was one wavelength (32.68 cm) long. This did not yield a suitable firing angle for the sidelobes when viewed in the theta plane. The respective size of the radiating helical element with respect to the ground plane suggested that not enough of a reflecting surface was being seen by the radiation. A design modification was then introduced whereby the dimensions of the reflecting surface sides was doubled thereby increasing the total surface area by a factor of four. Testing of this configuration showed that the desired sidelobes were now directed vertically with a 15 degree separation. A square reflector of length equal to two wavelengths provided too much projection angle above the horizontal. Successive trimming of the reflector dimensions brought the sidelobes back to an acceptable position. The optimized reflector side length was 1.75 wavelengths.

The dimensions of the reflecting surface were critical for as a threshold length was reached, an abrupt, major change in the antenna pattern resulted. Passing the threshold transformed the antenna from a double-lobed axial mode radiator to a double-lobed normal mode radiator.

The beamwidth of the sidelobes in the theta plane compared well with the theoretical values. The design objective was a beamwidth of 28.05 degrees but the achieved

beamwidth was somewhat larger at 34.5 degrees. A nearly uniform field pattern was achieved in the phi plane. Slight indentations in the field pattern occurred at approximately 120 degree intervals.

The resulting field patterns also indicated that the square reflecting ground plane produced fewer irregularities in the phi plane than in the theta plane. With additional reflecting surface area located in the corners of the reflector, several small sidelobes appeared which were not anticipated.

Examining the field patterns of the axial mode antenna, one finds a highly directional antenna. A gain margin of 14 dB was achieved in the theta plane over the dipole antenna of the tracked vehicle. The magnitude of the gain advantage was expected since the radiation had been confined to a small sector of interest. The beam mode design called for a single lobe to radiate axially with a half power beamwidth of 68 degrees. A slightly smaller beamwidth of 66 degrees was actually achieved.

No field pattern difficulties arose in connection with the size of the ground plane. A length of one wavelength was used for the length of each side of the reflector. In contrast to the normal mode helical antenna, the axial mode antenna was only one third as tall and about one half its size in circumference. Consequently, the radiating energy interacts with a much larger relative surface area.

One additional observation was made during the antenna range test sequences and that involved the uniformity of the field patterns while the helical antennas were being rotated. In all cases the transmitting dipole antenna was stationary and the receiving helix in motion. Developing both theta and phi field patterns required revolving the

helix about two different axis of rotation. The simplest rotation occurred during the phi plane pattern test and involved circular motion about the central axis of the helix. When the theta patterns were taken, the antenna rotated with its helical element parallel to the ground surface. In this configuration the large reflecting surface acted as a sail in catching the slight breezes causing some vertical motion. Since the helical element was in a horizontal position, the moment arm action of the helix also contributed to the vertical oscillatory action. Comparison of patterns taken with no wind and those taken with a slight breeze acting upon the antennas indicated no deviations in the field patterns. These findings of antenna field pattern response under conditions of a nonstationary platform indicate that the helical antennas should be suitable for inclusion on tracked vehicles which are maneuvering on the field of play.

B. TEST RESULTS FROM FORT HUNTER LIGGETT

Field pattern results obtained from the antenna range tests indicated that each helical antenna was radiating in a configuration which would enhance the operational efficiency of the Range Measurement System. Further testing was conducted at Fort Hunter Liggett to measure the effect of integrating the prototype helical antennas into an operational environment.

Two transmission test periods were conducted in conjunction with experiments determining the effects of multipathing which introduce range errors and degrade the system's performance. The conditions for the test periods were diverse and included testing during mid-day as well as during the evening. The interrogator A station used for the

daylight experiments was the mobile A station and was positioned at Camp Roberts. For the evening experiments, a fixed position A station was used and its location was at Fort Hunter Liggett. Mobile B units were used to respond to the interrogating signal during both experiments.

Responses at the A station during the daylight tests when the dipole antenna was used were sporadic at best. The received signal would yield a ranging pulse but a sustained response could not be maintained. After exchanging the axial mode helical antenna for the dipole, a ranging pulse was obtained and maintained. The characteristics of the pulse included a rapid rise and fall time to and from the designated voltage level. During the ranging interval, the shape of the pulse remained essentially rectangular. Ranging information was received at both the 72 inch and the 36 inch transmission level of the tripod for the helical antenna. Identical results were obtained when the normal mode antenna was used.

Test site locations for the daylight experiments included positions below the elevational level of the A station as well as test sites at or about the same elevation on an adjacent ridge line. In each case only the helical antennas allowed a range pulse to be obtained. Calculations made during these tests showed that at least a 6 dB gain advantage for the helical antennas accounted for the successful transmissions when free-space attenuation was considered. Later experimentation into the area of multipathing resulted in the discovery that the B units were improperly calibrated. Even though tests were conducted with equipment deviating from correct calibration standards, the gain advantage of the helical antennas over dipole antennas was sufficient for the receipt of correct ranging information. Test site distances were confined to 600

meters or 1200 meters from the A station during daylight experimentation.

Tests conducted during the evening met with limited success due to faulty B unit transponders. Range information was obtained only during the initial portion of the test time period but the results were again similar to the daytime experiments. It became apparent that high gain helical antennas with specific directional properties could enhance the system's operation when RMS equipment was operating properly and could also provide a safety margin enabling the system to continue in operation with marginally calibrated equipment.

V. CONCLUSIONS

The choice of an antenna is one decision which must be made by all systems engineering designers. Factors which affect the ultimate decision include simplicity of form, functional capability and impact on the system as a whole. Dipole antennas meet the criteria of simplicity and functional capability but fall short of design expectations when their effectiveness is considered as a radiator for the Range Measurement System. Unique terrain features associated with the Fort Hunter Liggett test area detract significantly from the performance of dipole antennas. Specifically, radiation is directed towards locations where few A stations may be expected to be located and, hence, reduce their effectiveness to the system.

Simple antennas can be designed to replace the vehicle dipole antenna and increase the radiation effectiveness by selectively pointing the antenna beams in directions of highly probable A station locations. Such antennas are helical antennas of which either the axial mode or normal mode may be selected. Each helical antenna has a gain advantage over the vehicle dipole. The physical size of each helix is small to permit a low antenna profile to be achieved. The larger normal mode helix can be mounted vertically in a rear corner of the tank turret while the axial mode antenna must be mounted at the periphery of the tracked vehicle. A configuration employing the axial mode helix requires four antennas to be installed. Each axial helix must be pointed or directed such that an angle of 15 degrees is achieved between the helix axis and the horizontal.

The design of the antennas also permits rapid inclusion of the helical antennas into the RMS telemetry system at Fort Hunter Liggett as the helical antennas are impedanced matched tc 50 ohm coaxial cables.

VI. RECOMMENDATIONS

Directional helical antennas provide better service to the RMS system and are suitable replacements for the vehicle dipole. Results of testing and experiments conducted to date reflect this superiority but certain additional testing should be conducted. An additional test period should include performance studies of the antennas mounted and radiating on tanks while the tracked vehicles are maneuvering on the field of play. Data can be accumulated reflecting the vibrational effects and the jarring motions of tanks on the antennas. This same test period should be conducted with a protective covering or sleeve encasing the helical element. These structures are somewhat fragile and a transparent radome would assist in prolonging the lifetime of the antenna and decreasing the requirements for daily maintenance.

The manufacture of the helical element and its associated support structure is not difficult. This design benefits from the noncritical aspect of the tolerances of the physical antenna parameters in order for achievement of the particular mode of radiation desired. Each antenna design is designated on the Spacing-Circumference Chart as not being delicately balanced between the axial mode and the normal mode patterns. Slight deviations from the suggested antenna dimensions will not produce significant changes in the antenna pattern. Also, slight dimensional variations will not result in widely fluctuating SWR values as the testing on the Network Analyzer showed a stable range of reflection coefficient values over the 10 MHz frequency test band.

Positioning of the axial mode helix array around the periphery of the tank is depicted in Figure 6.

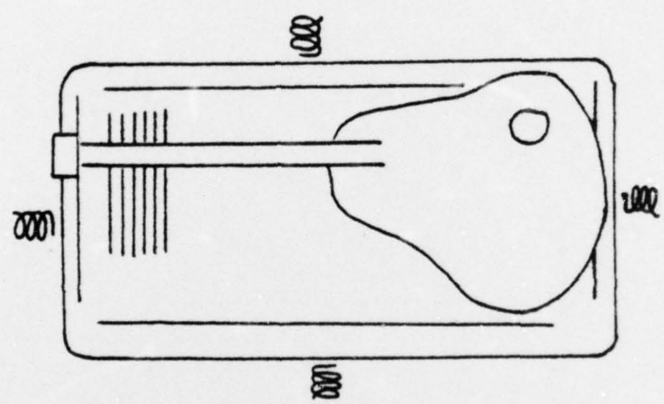

Figure 6 - AXIAL MODE CONFIGURATION

APPENDIX A

SMITH CHARTS

Reflection coefficients are plotted on Smith Charts for each helical antenna. Values for K were obtained over a 10 MHz bandwidth directly from the Network Analyzer.

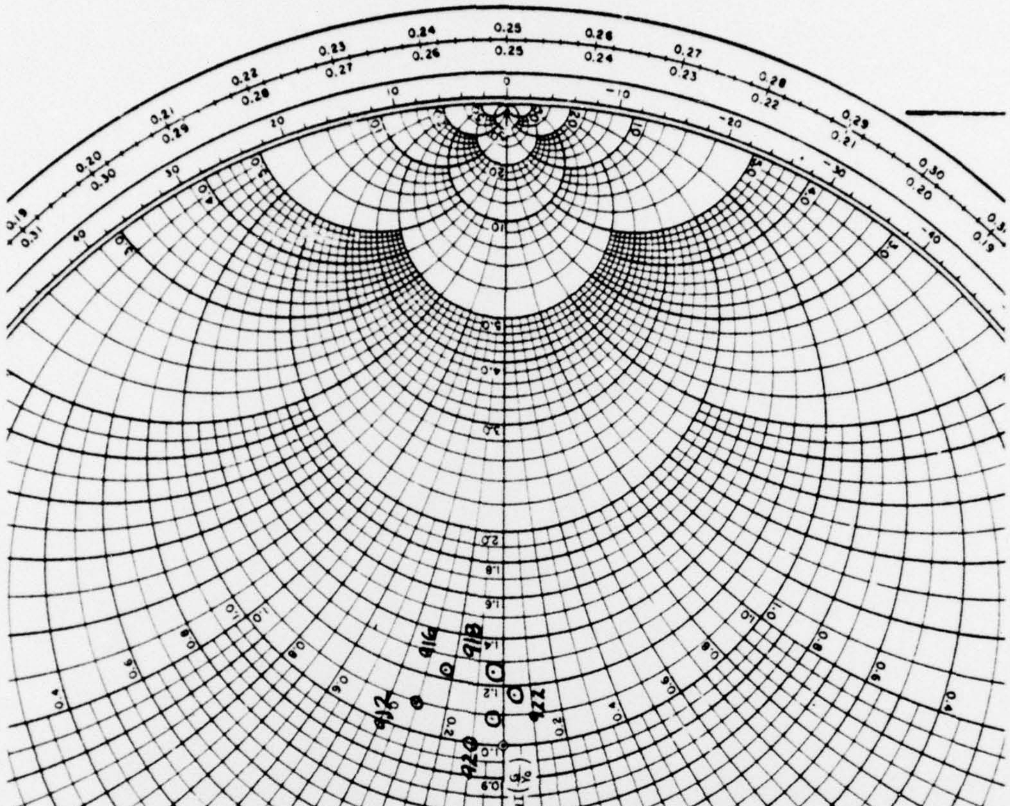

Figure 7 - NORMAL MODE VSWR DATA

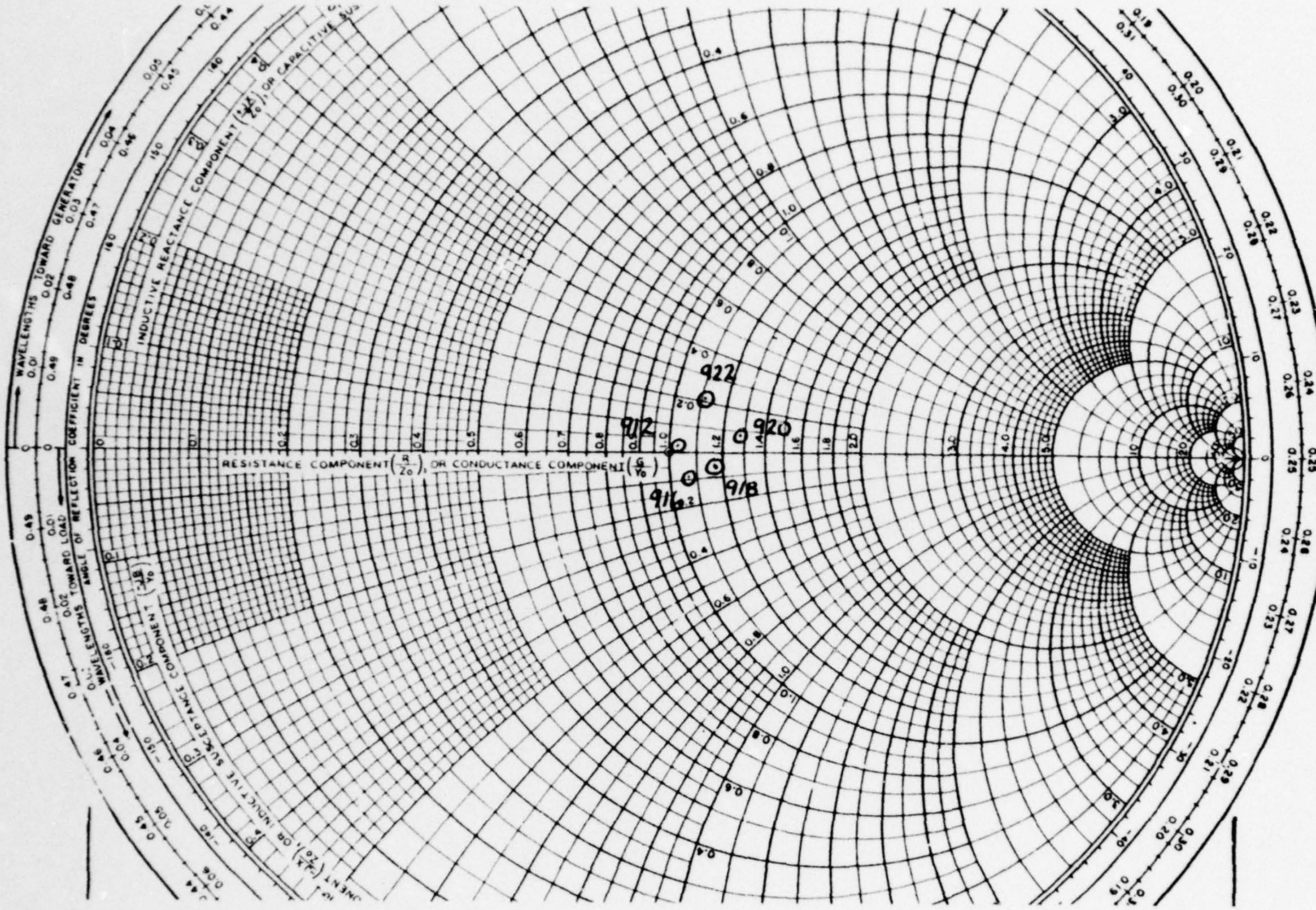

Figure 8 - AXIAL MODE VSWR DATA

APPENDIX B

FIELD PATTERNS

Polar field plots are presented here. Recordings were obtained for each helical antenna showing the theta and phi plane patterns. The Scientific-Atlanta Model 1533 Polar Recorder was used to plot the field patterns.

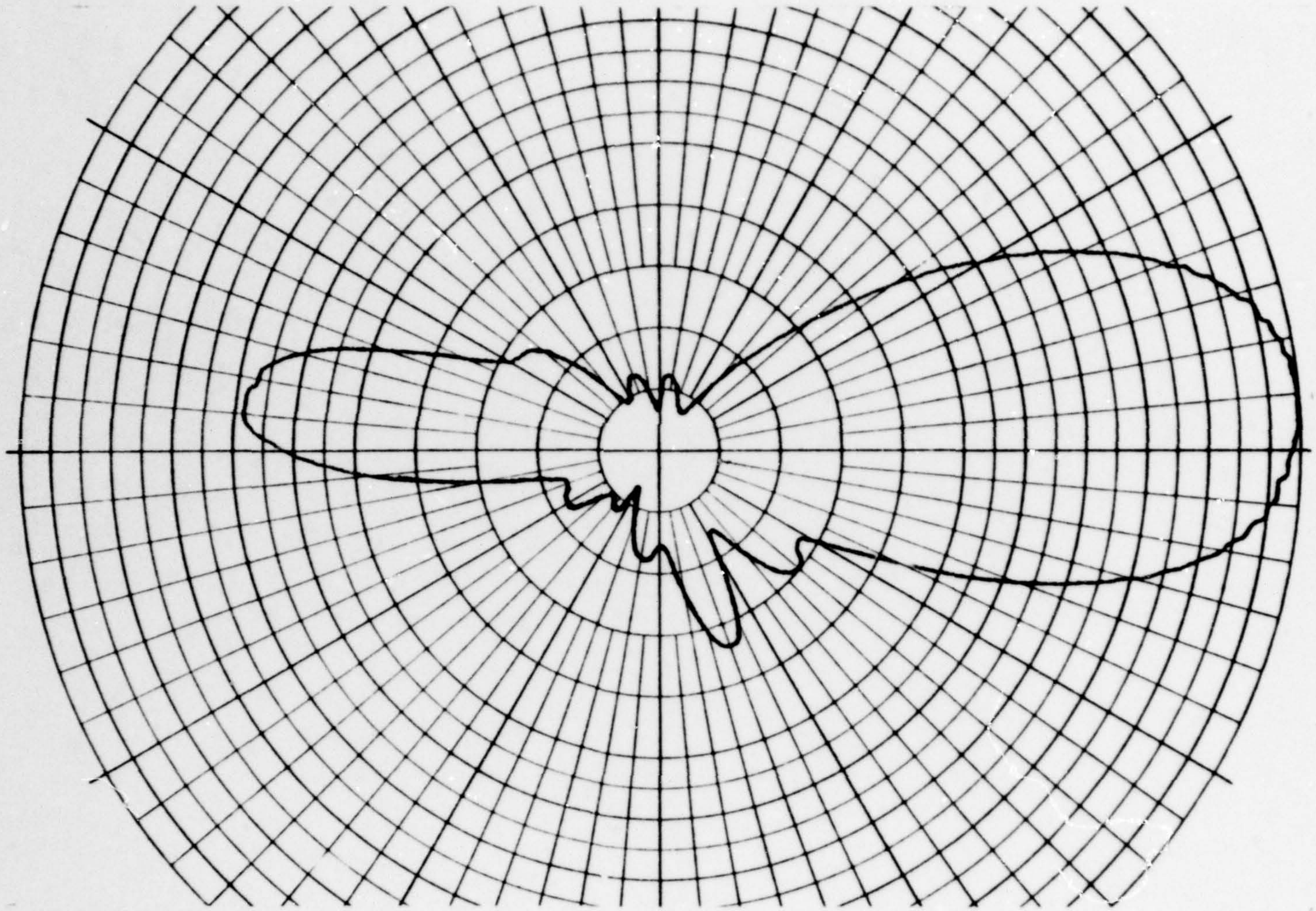

Figure 9 - NORMAL MODE E THETA FIELD PATTERN

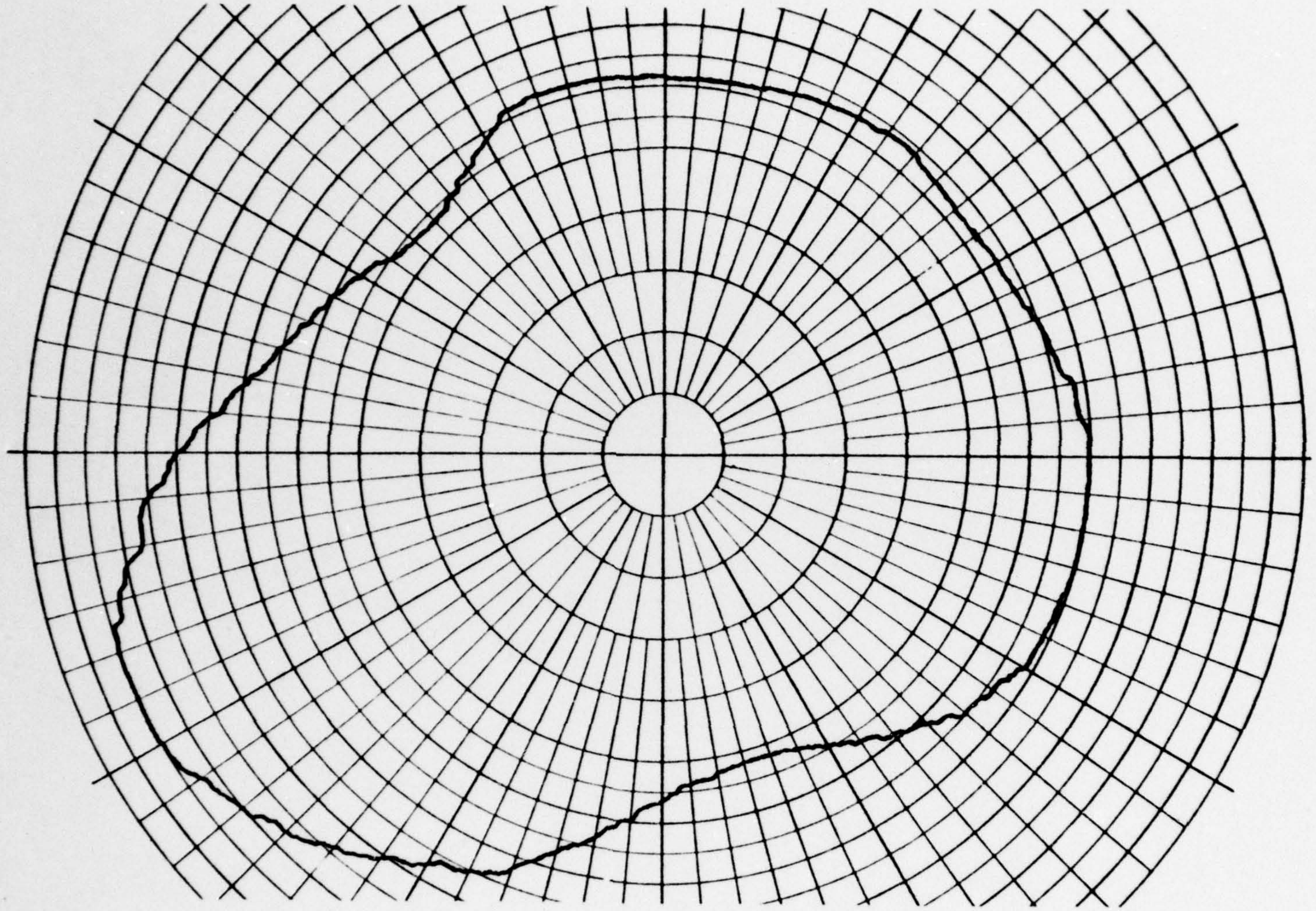

Figure 10 - NORMAL MODE E PHI FIELD PATTERN

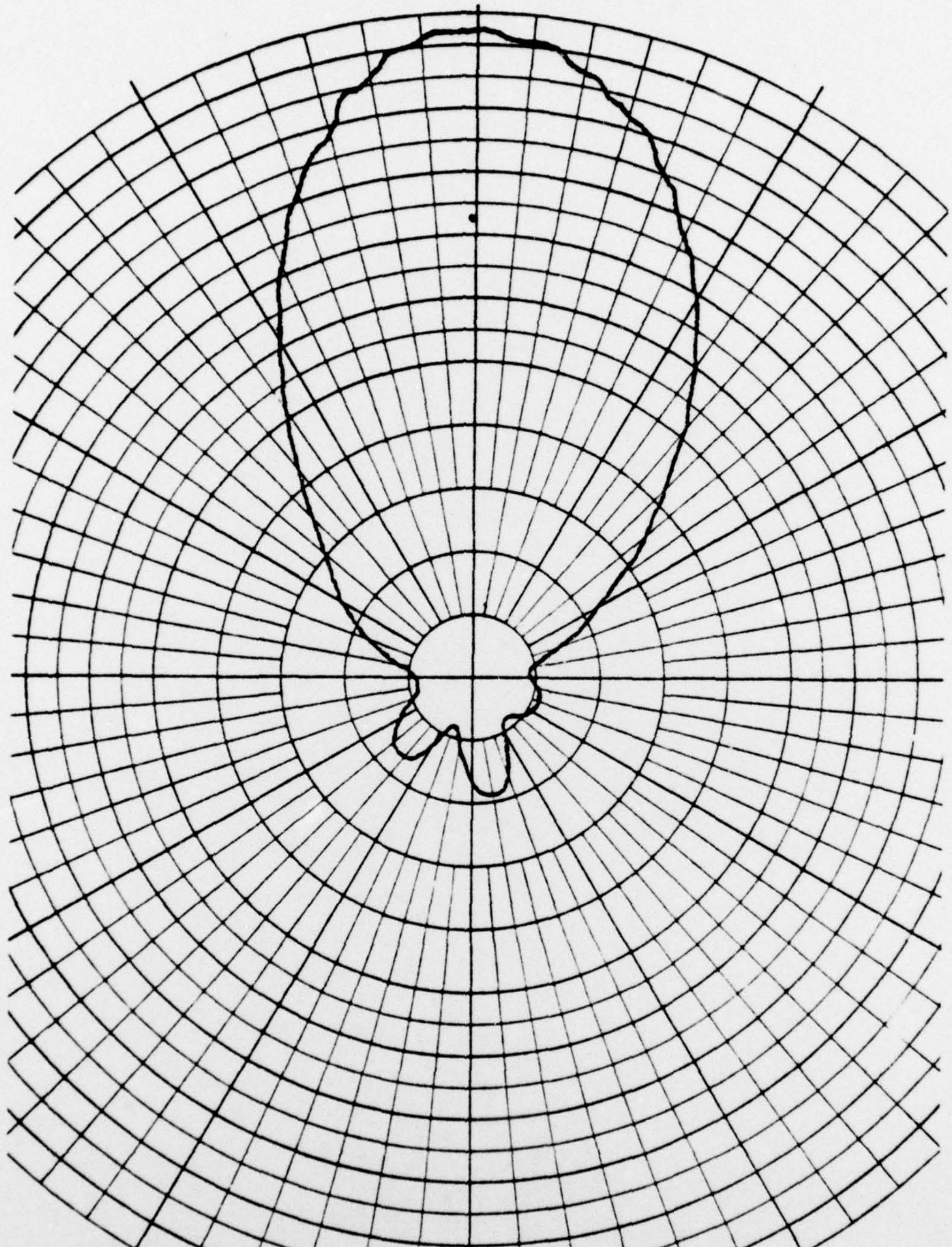

Figure 11 - AXIAL MODE E THETA FIELD PATTERN

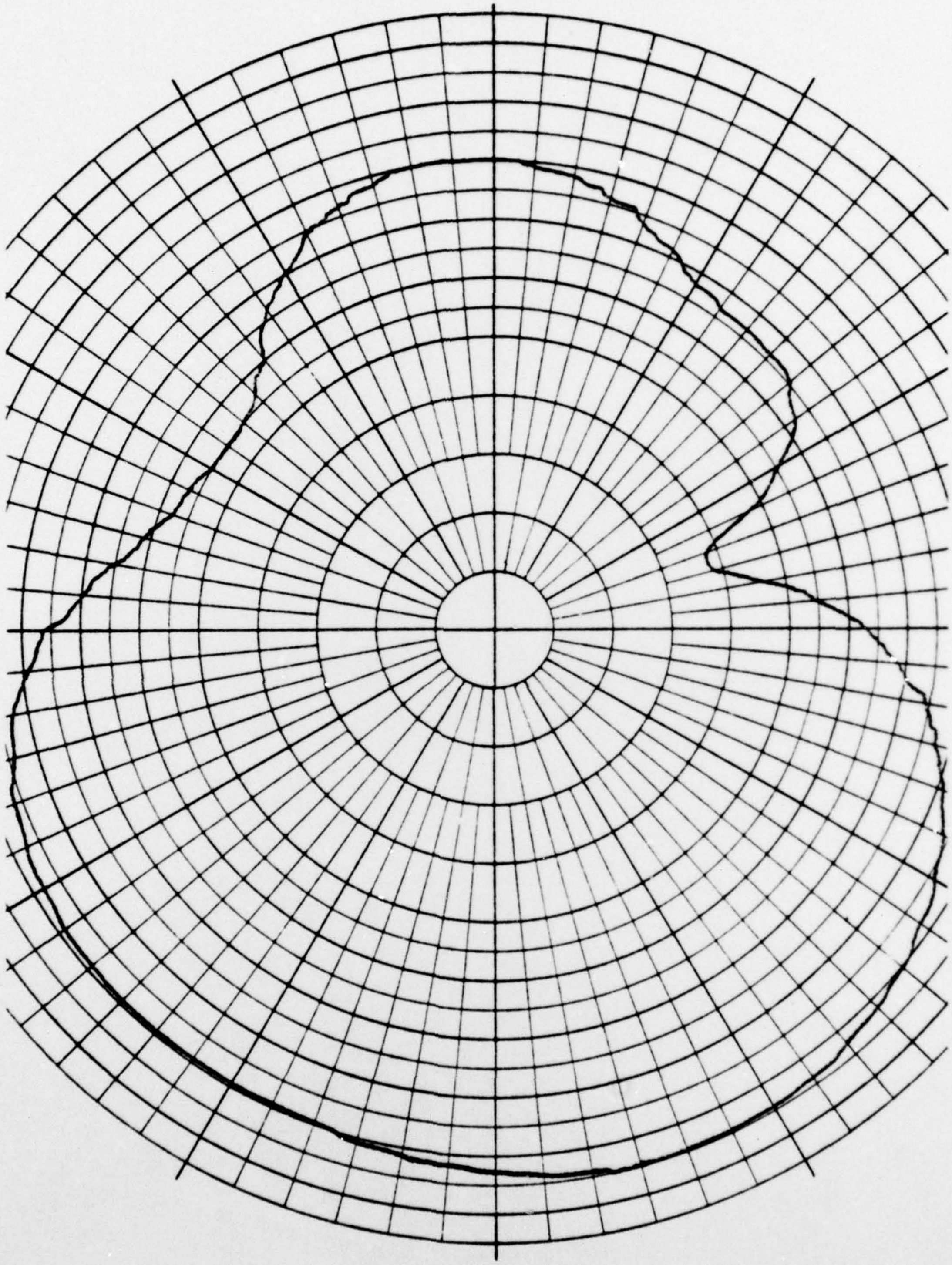

Figure 12 - AXIAL MODE E PHI FIELL PATTERN

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